LASER-PRODUCED PLASMA SPECTROSCOPY OF MEDIUM TO HIGH-Z ELEMENTS IN THE 2 TO 9 NM SPECTRAL REGION

Elaine Long[1], Chihiro Suzuki[2] , John Sheil[1], Elgiva White[1], Takamitsu Otsuka[3], Ragava Lokasani[1], Bowen Li[1], Robert Stefaniuk[1], Paul Sheridan[1], Paddy Hayden[4], Emma Sokell[1], Gerry O'Sullivan[1], Fergal O'Reilly[1] & Padraig Dunne[1]

[1]Atomic, Molecular, Plasma Physics and Spectroscopy Group, School of Physics, University College Dublin
[2]National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan
[3]Utsunomiya University, Japan
[4]National Centre for Plasma Science & Technology and School of Physical Sciences, Dublin City University

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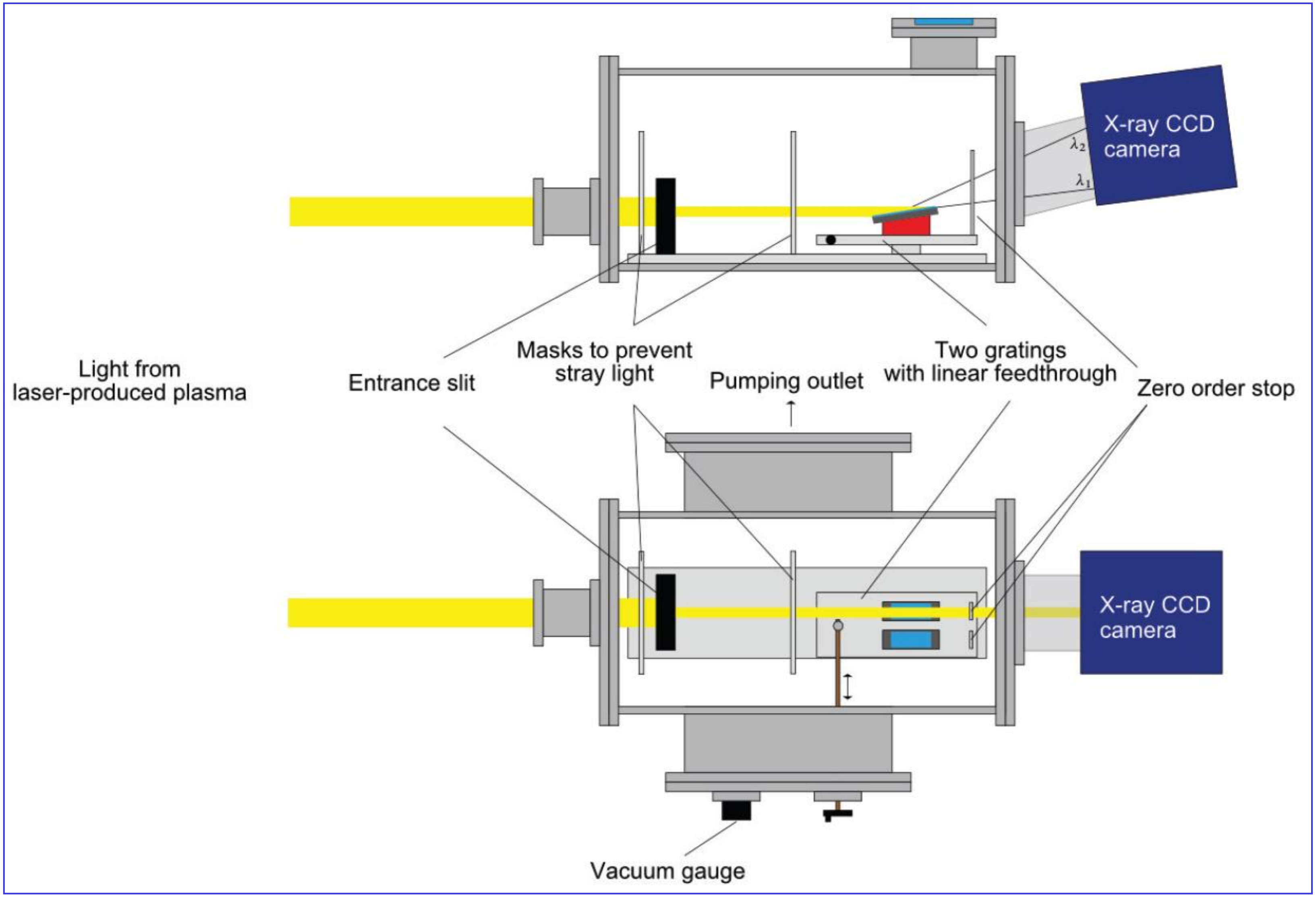
Outline

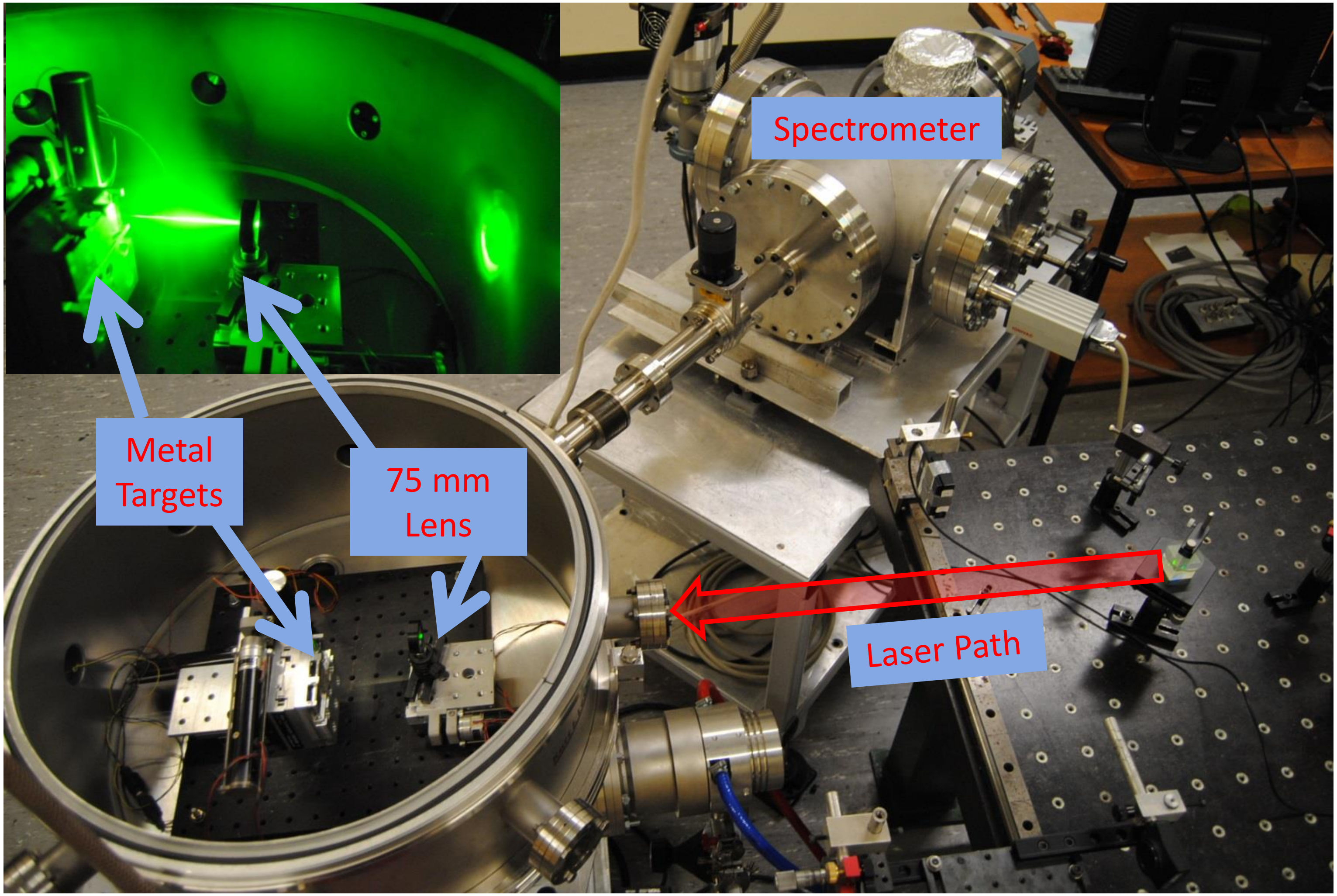
- Emission Spectroscopy
  - Experimental Set-up
  - Targets used
  - Spectra obtained
  - Cowan Code Calculations
- Absorption Spectroscopy
- Plasma Imaging

Schematic Diagram of Spectrometer



(courtesy of Takamitsu Otsuka)

Emission Spectroscopy Set-Up



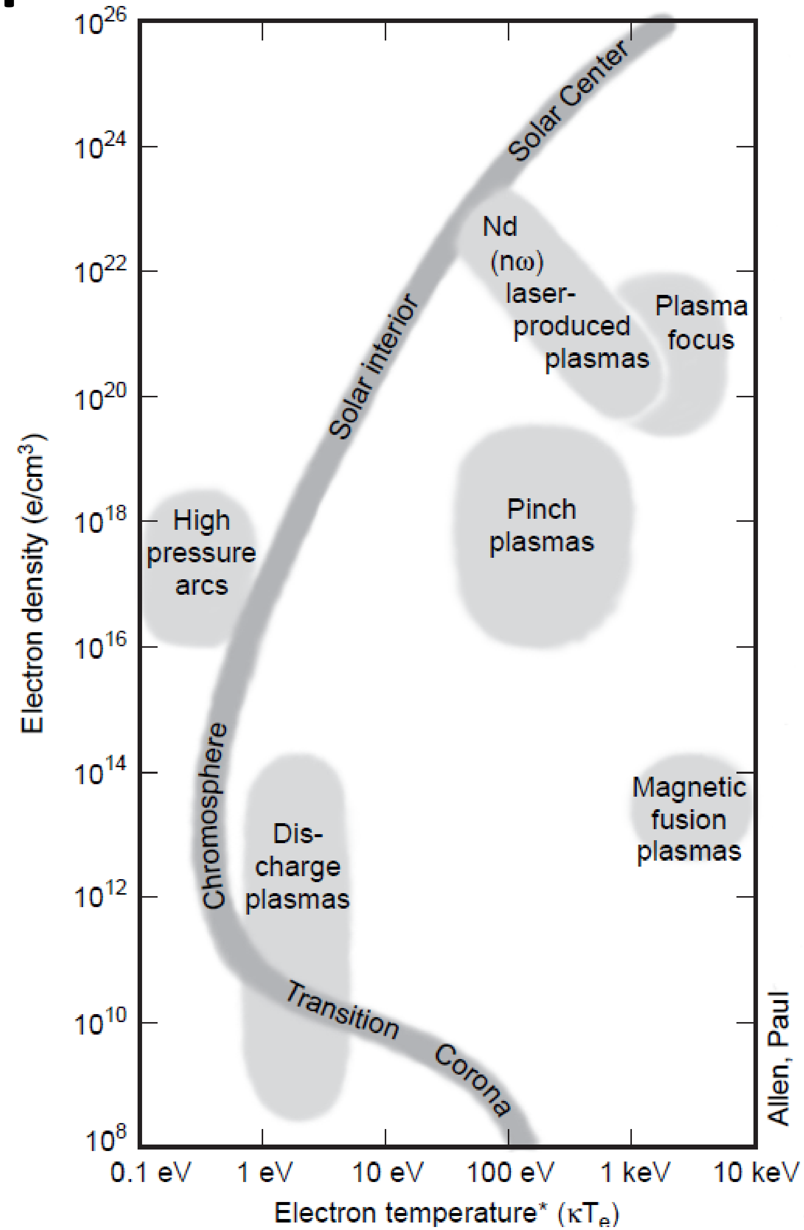
Plasma Properties

Temperature depends on laser power density (Φ)

$$T_e(eV) \approx (\lambda^2 \Phi)^{3/5}$$

Electron density $10^{19} – 10^{21}$ cm^{-3} depending on laser wavelength

$$n_{ec} \sim \frac{10^{21}}{\lambda^2} (\text{cm}^{-3})$$



Professor David Attwood, Univ. California, Berkeley

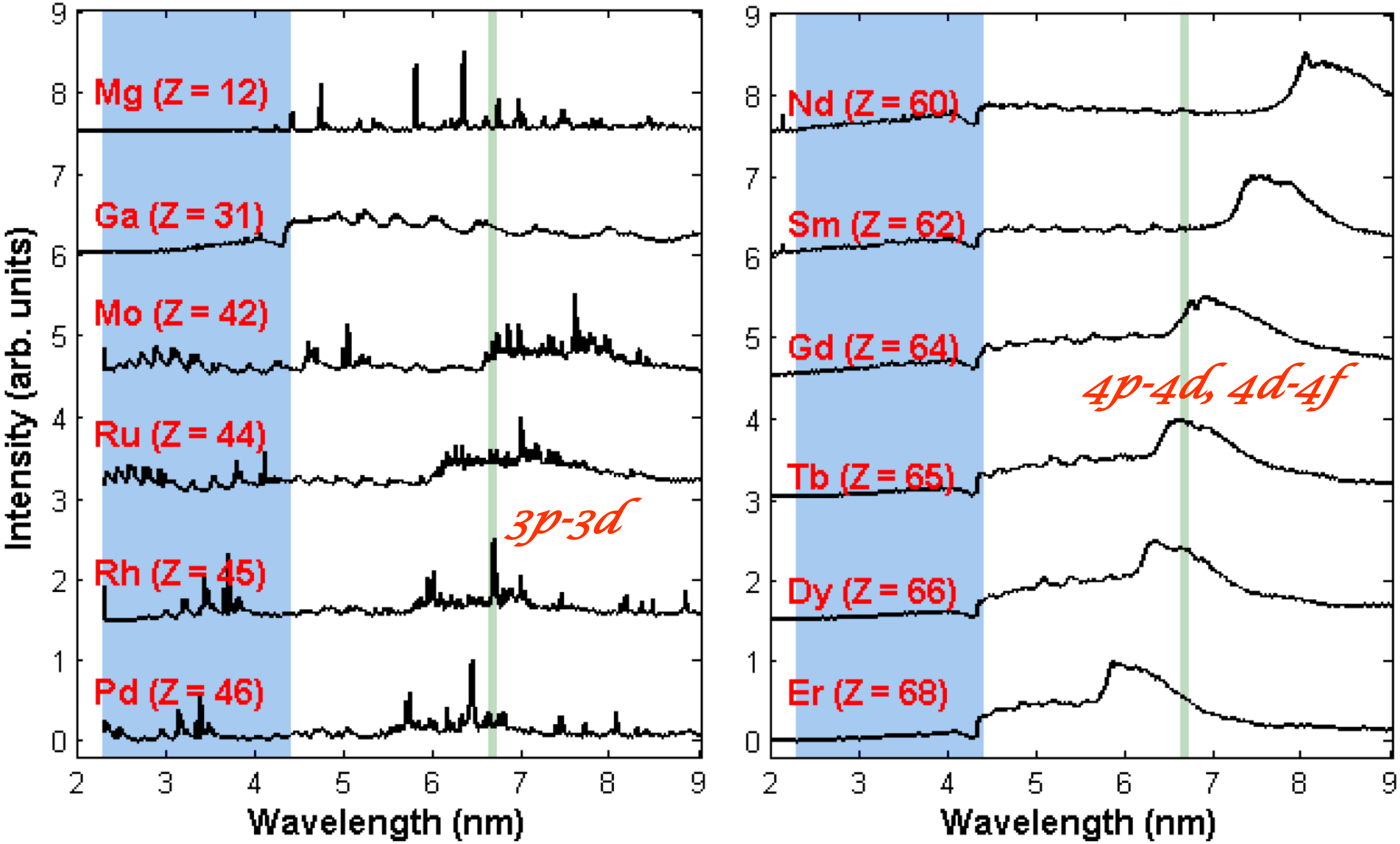
Targets used for Emission Spectroscopy

hydrogen 1 H 1.0079																		helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122												boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	**magnesium 12 Mg 24.305**												aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	**gallium 31 Ga 69.723**	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		**yttrium 39 Y 88.906**	**zirconium 40 Zr 91.224**	**niobium 41 Nb 92.906**	**molybdenum 42 Mo 95.94**	technetium 43 Tc [98]	**ruthenium 44 Ru 101.07**	**rhodium 45 Rh 102.91**	**palladium 46 Pd 106.42**	silver 47 Ag 107.87	cadmium 48 Cd 112.41	**indium 49 In 114.82**	**tin 50 Sn 118.71**	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	**hafnium 72 Hf 178.49**	tantalum 73 Ta 180.95	**tungsten 74 W 183.84**	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	**platinum 78 Pt 195.08**	gold 79 Au 196.97	mercury 80 Hg 200.59	**thallium 81 Tl 204.38**	**lead 82 Pb 207.2**	**bismuth 83 Bi 208.98**	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 * *	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

* Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	**neodymium 60 Nd 144.24**	promethium 61 Pm [145]	**samarium 62 Sm 150.36**	europium 63 Eu 151.96	**gadolinium 64 Gd 157.25**	**terbium 65 Tb 158.93**	**dysprosium 66 Dy 162.50**	holmium 67 Ho 164.93	**erbium 68 Er 167.26**	**thulium 69 Tm 168.93**	**ytterbium 70 Yb 173.04**
* * Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

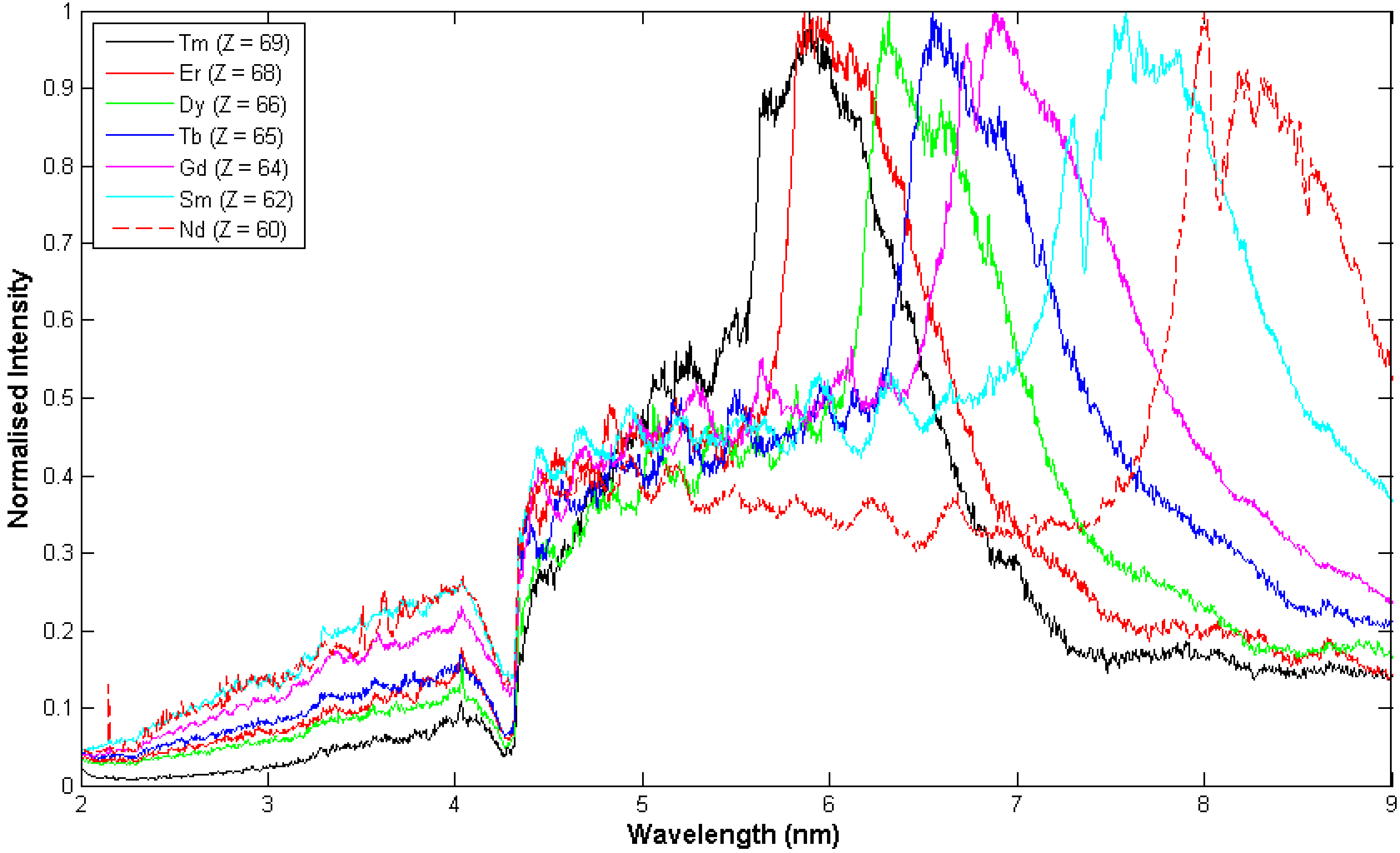
$^{A}_{Z}X$

Sample of Spectra Recorded



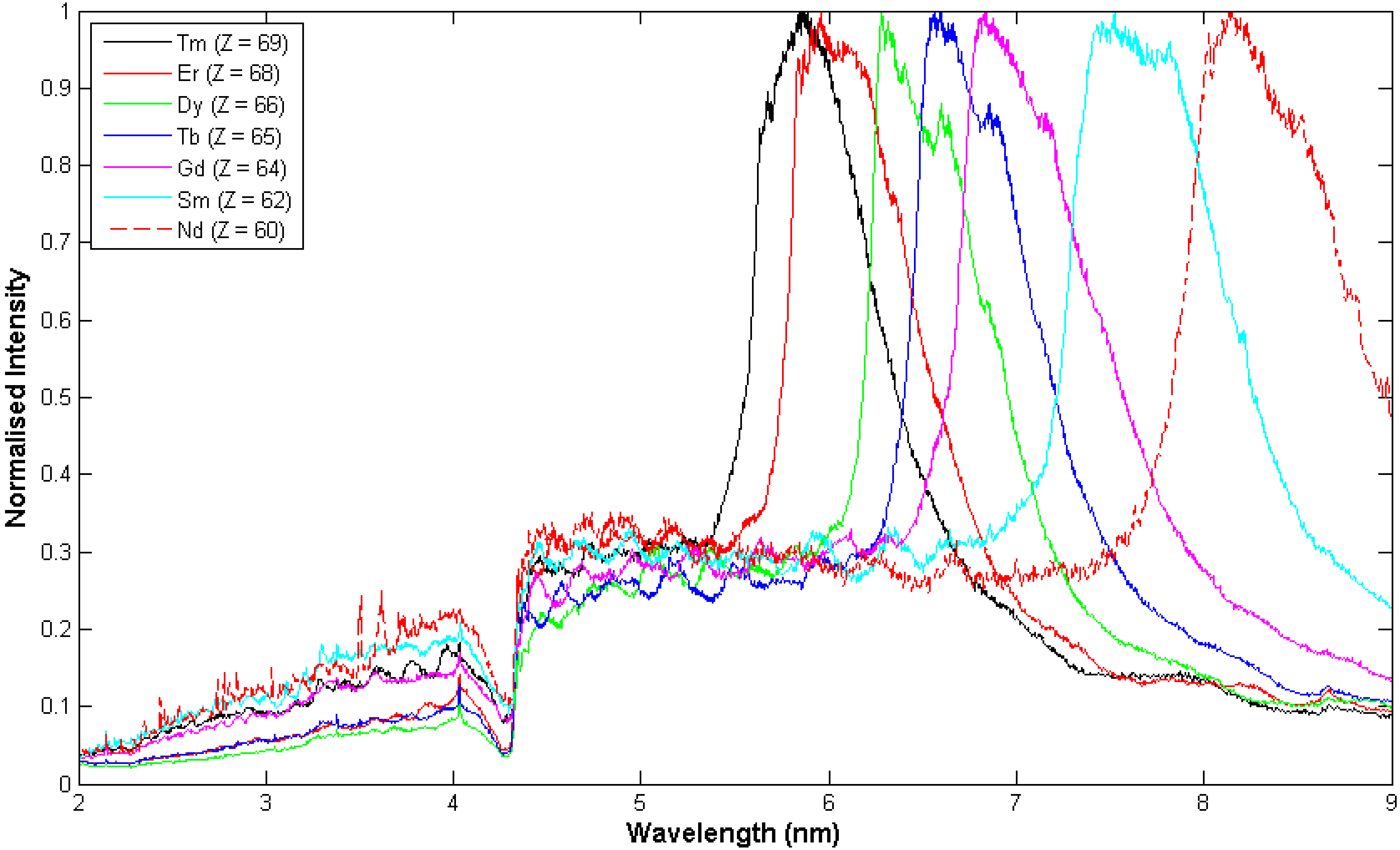
Experimentally recorded spectra of medium to high-Z elements with 8 ns, 1064 nm pulse (power density of ~10^{13} Wcm^{-2}).

Spectra of Lanthanides using 8 ns pulse



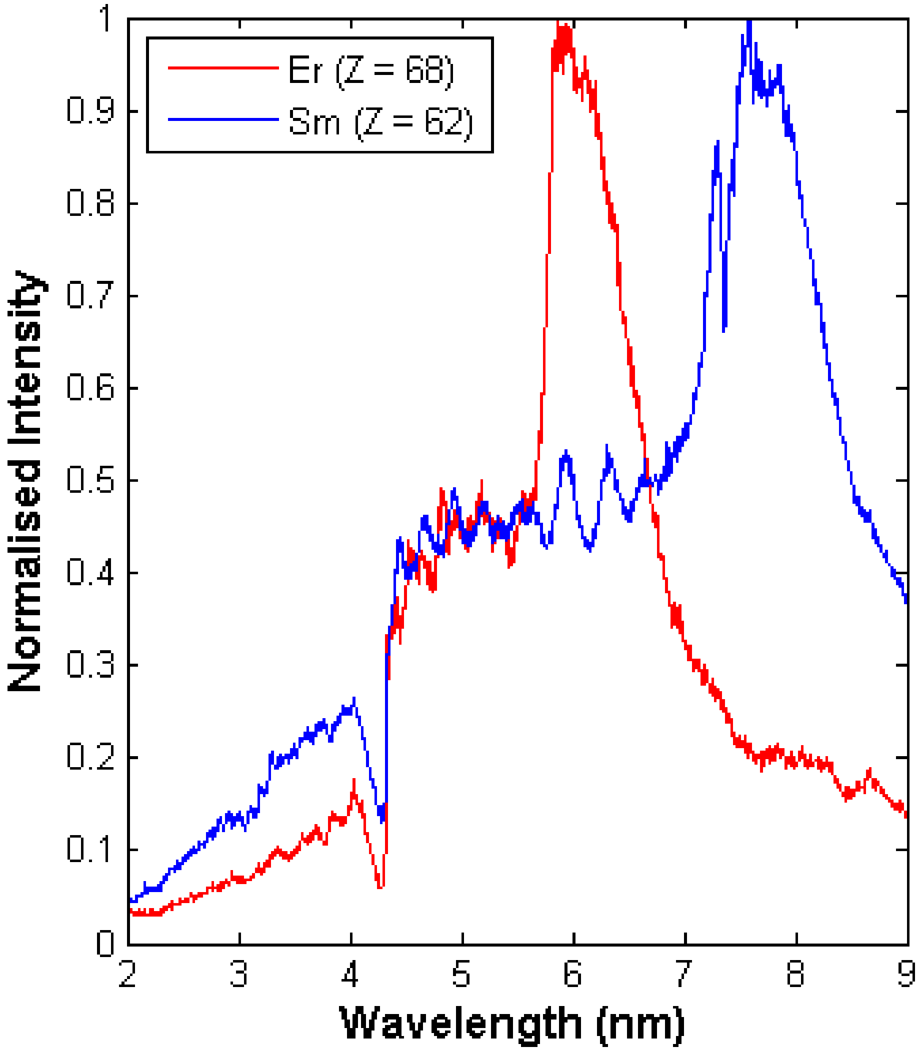
(E ~ 600 mJ , power density ~ 1X10^{13} Wcm^{-2})

Spectra of Lanthanides using 180 ps pulse

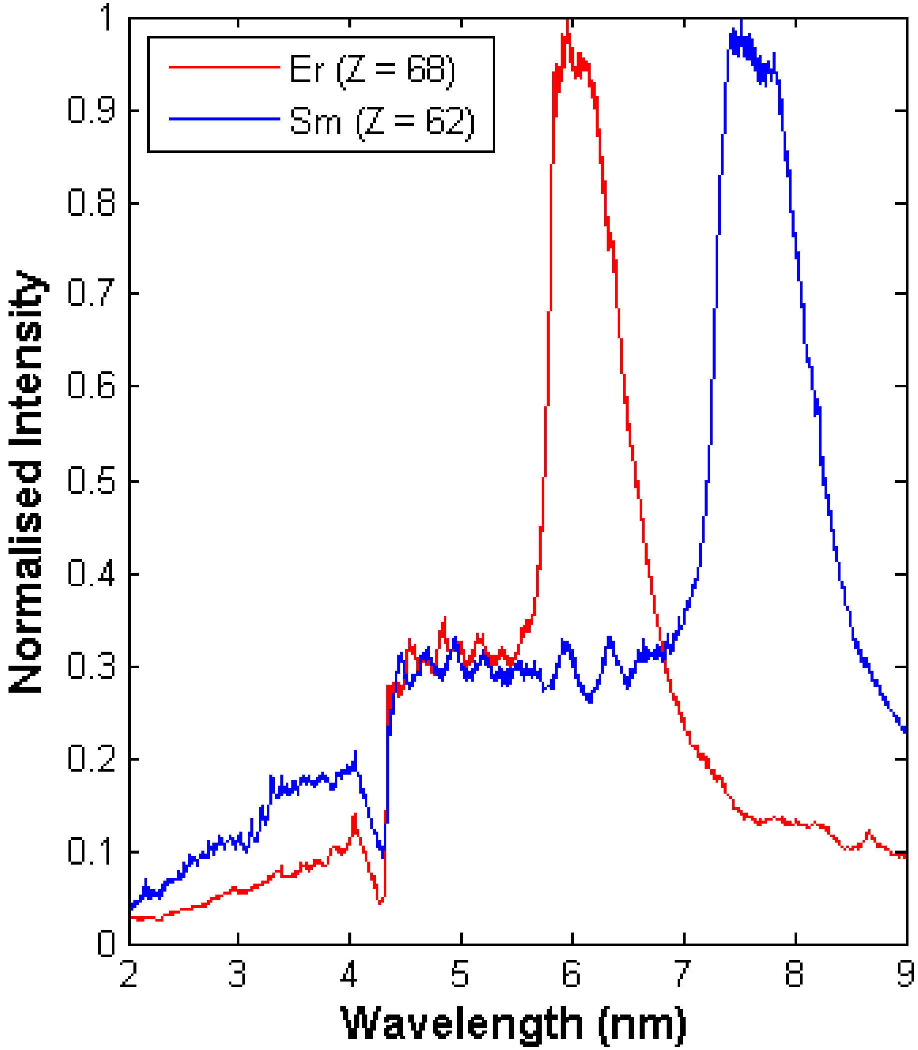


(E ~ 250 mJ, Power Density ~ $4X10^{14}$ Wcm^{-2})

Spectra of Lanthanides (long and short pulse)

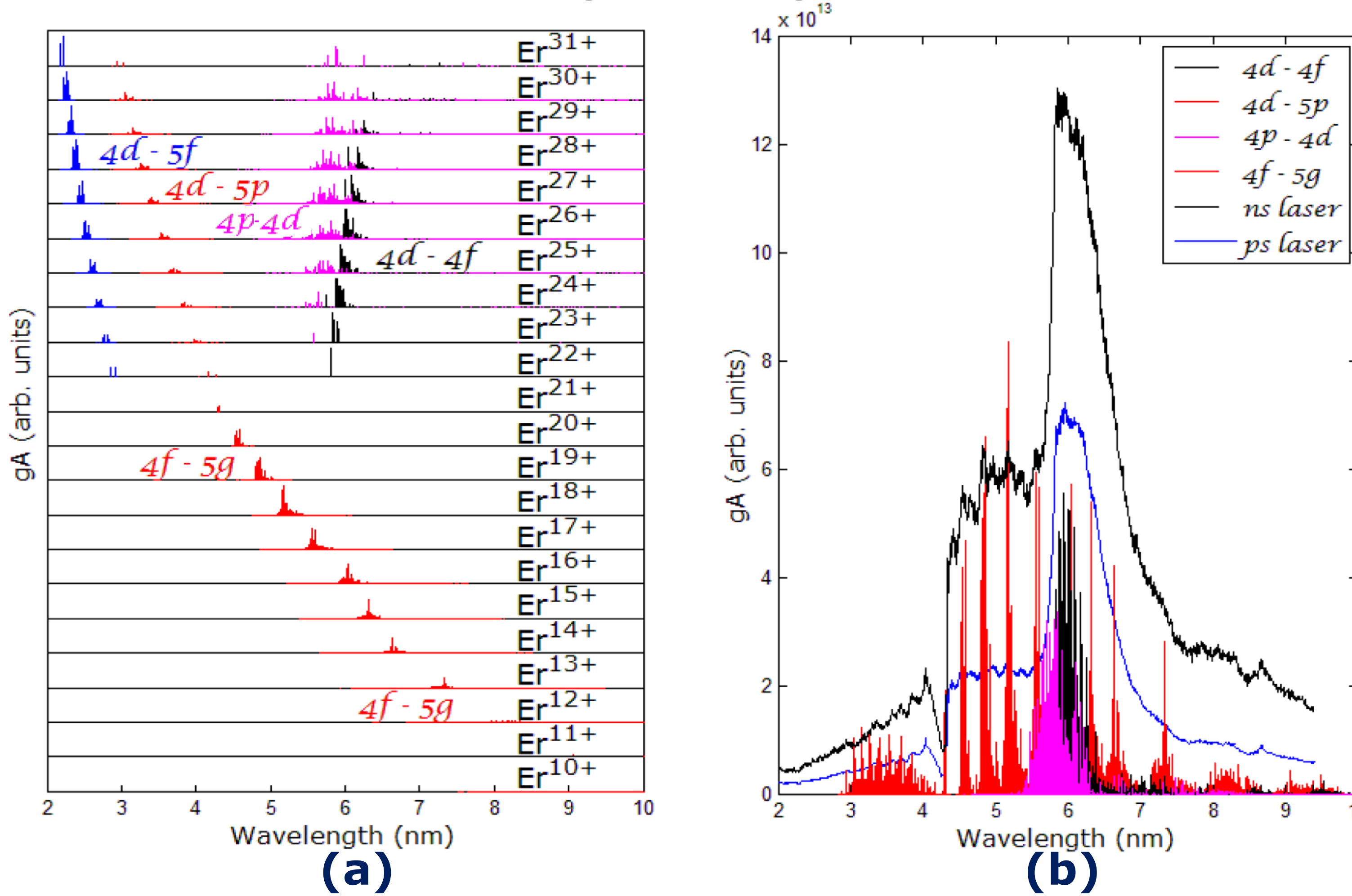


(8 ns)



(180 ps)

Calculated & Experimental Spectra of Er (Z=68)



(a) shows Hartree-Fock with CI calculations performed using the Cowan Suite of Codes for erbium. Figure 8 (b) shows both the calculated and experimental spectra for an erbium target.

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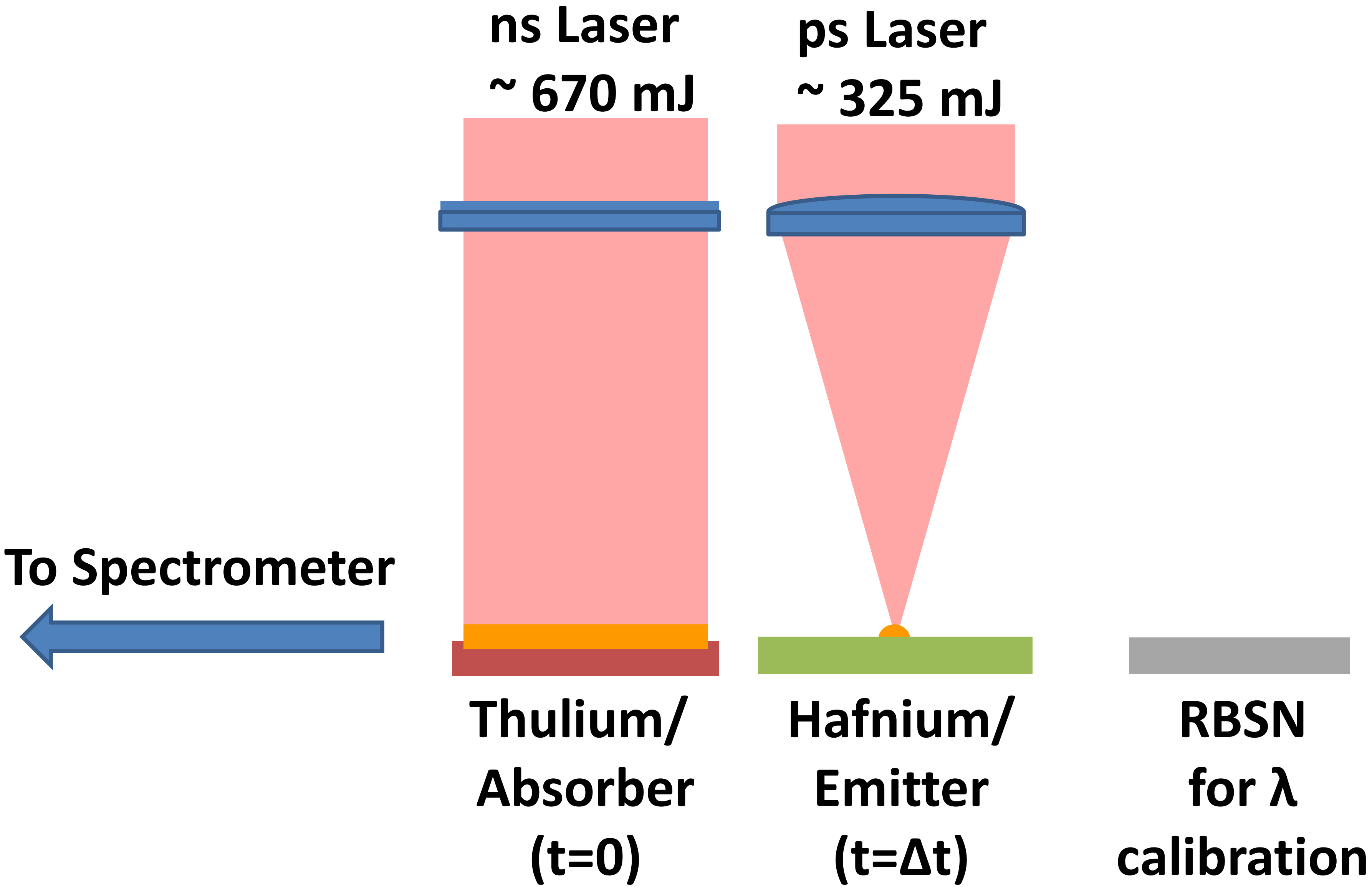
Photoabsorption of Thulium



Photoabsorption of Thulium

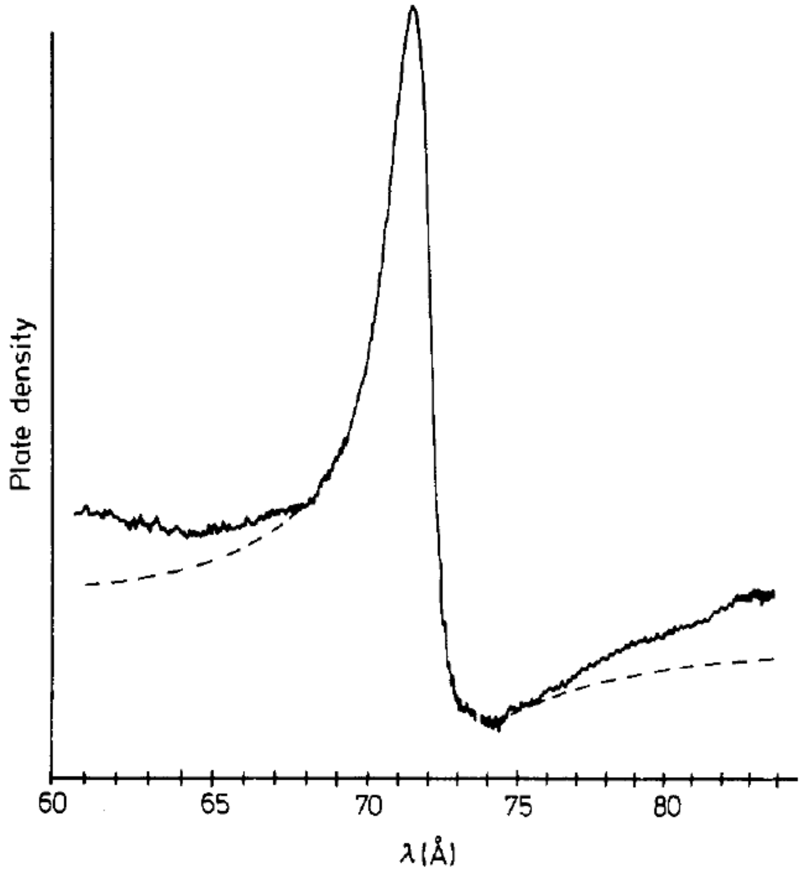
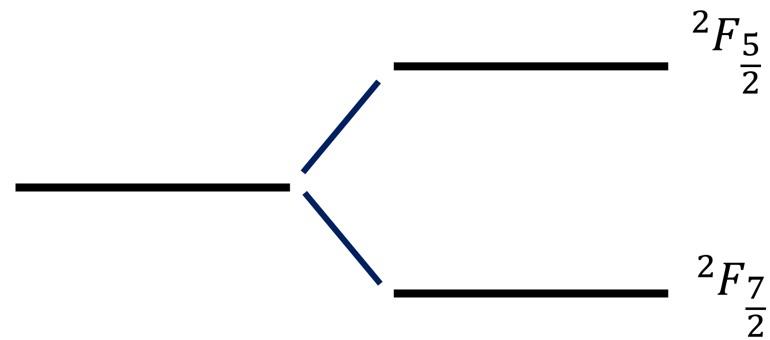


Figure 2. The 4d photoabsorption spectrum of Tm I. Full curve, data for Tm vapour; broken curve, Fano profile fit, where it deviates from the observed spectrum. Profile parameters: $q = 3{\cdot}6 \pm 0{\cdot}4$, $\Gamma = 2{\cdot}8 \pm 0{\cdot}2$ eV, $E_0 = 173{\cdot}15 \pm 0{\cdot}1$ eV, $\sigma_b =$ constant 1, $\sigma_a(\epsilon) =$ constant 2.



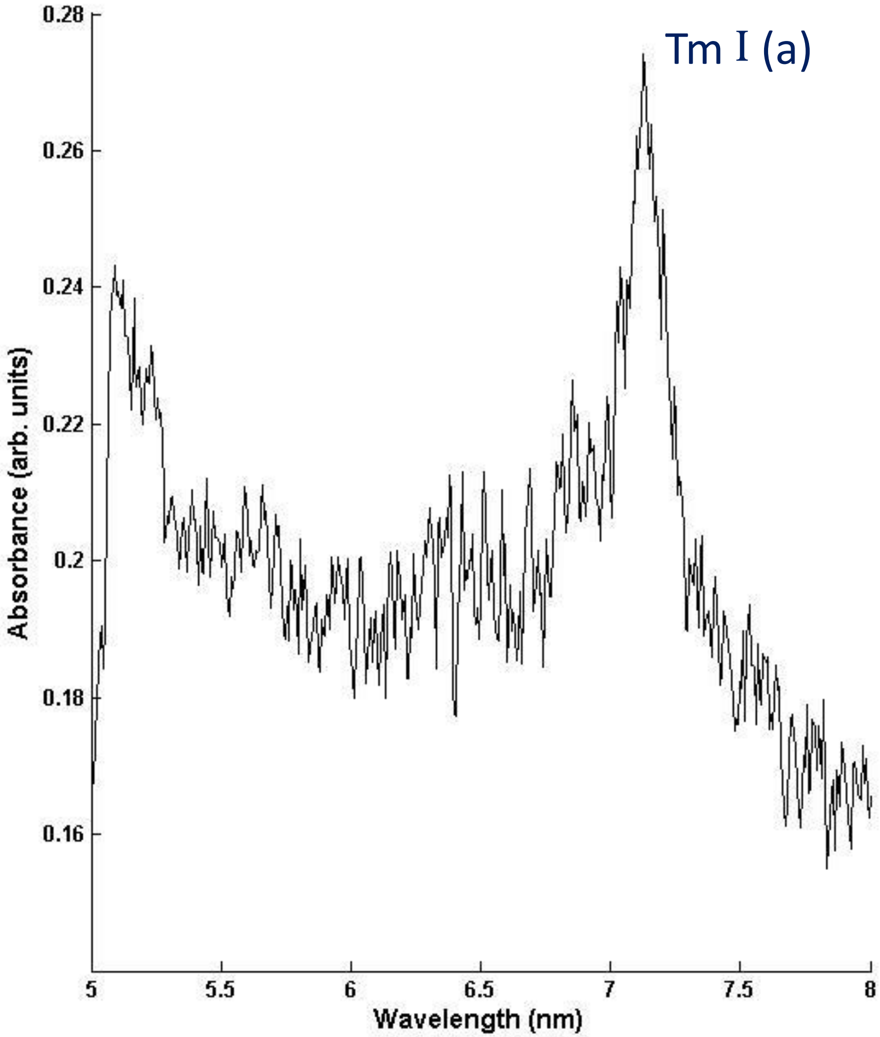
Tm I (a) $4d^{10}4f^{13}\,{}^2F_{\frac{7}{2}} \longrightarrow 4d^9 4f^{13}\,{}^2D_{\frac{5}{2}}$

Tm I (b) $4d^{10}4f^{13}\,{}^2F_{\frac{5}{2}} \longrightarrow 4d^9 4f^{13}\,{}^2D_{\frac{3}{2}}$

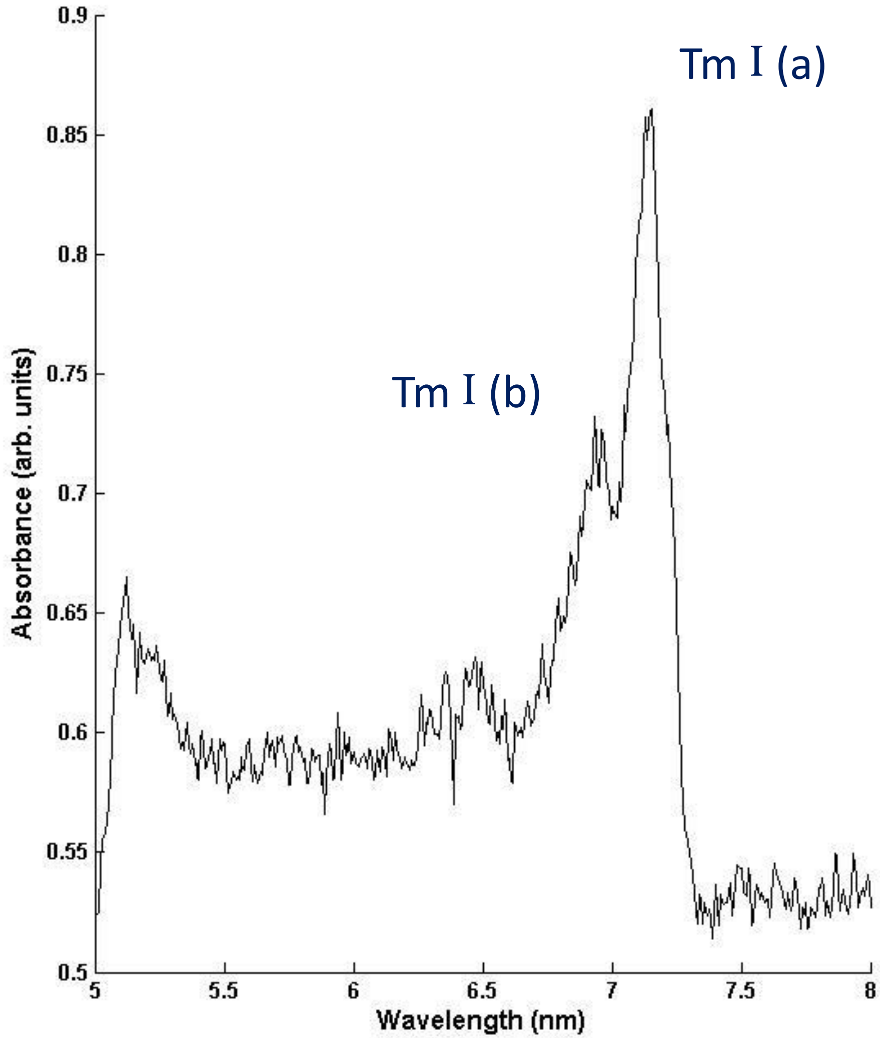
Tm I	$4p^6 4d^{10} 5s^2 5p^6 6s^2 4f^{13}$
Tm II	$4p^6 4d^{10} 5s^2 5p^6 6s 4f^{13}$
Tm III	$4p^6 4d^{10} 5s^2 5p^6 4f^{13}$
Tm IV	$4p^6 4d^{10} 5s^2 5p^6 4f^{12}$

Radtke's Paper – "On the character of the intense 4d→f resonances in atomic La and Tm"

Thulium; 4d-4f, 1000 & 400 ns

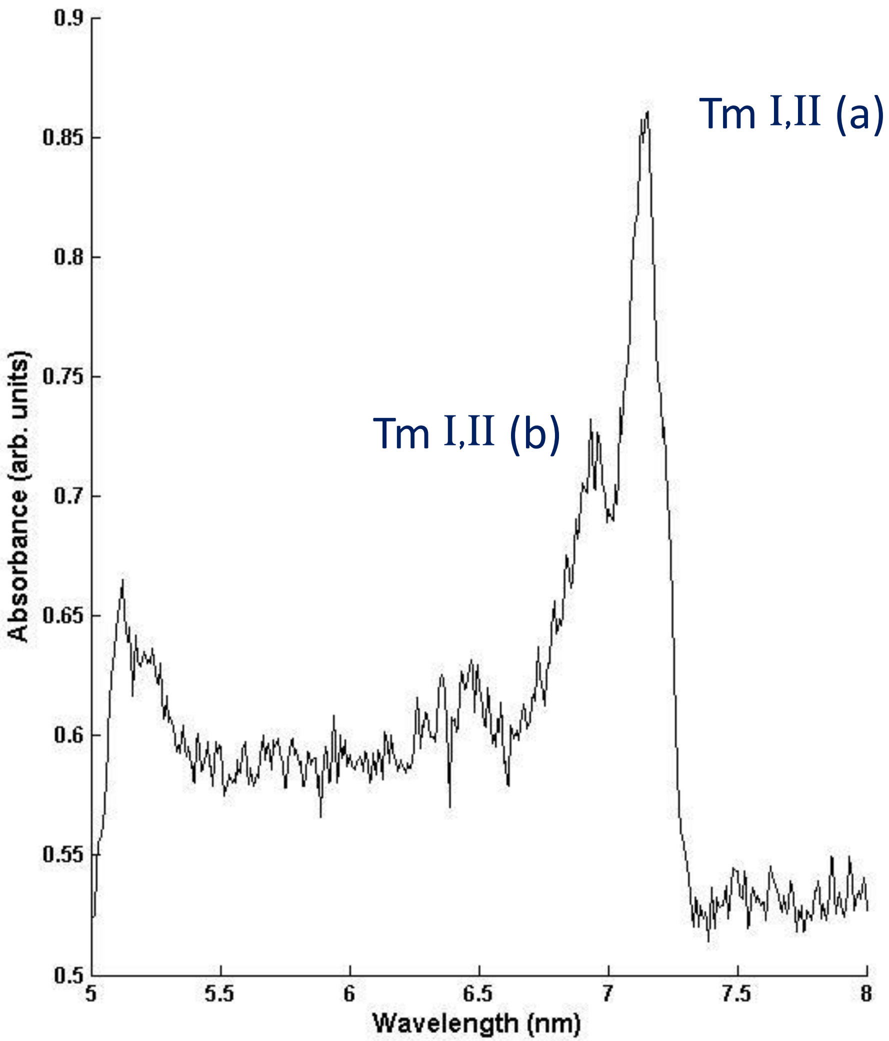


1 μs delay

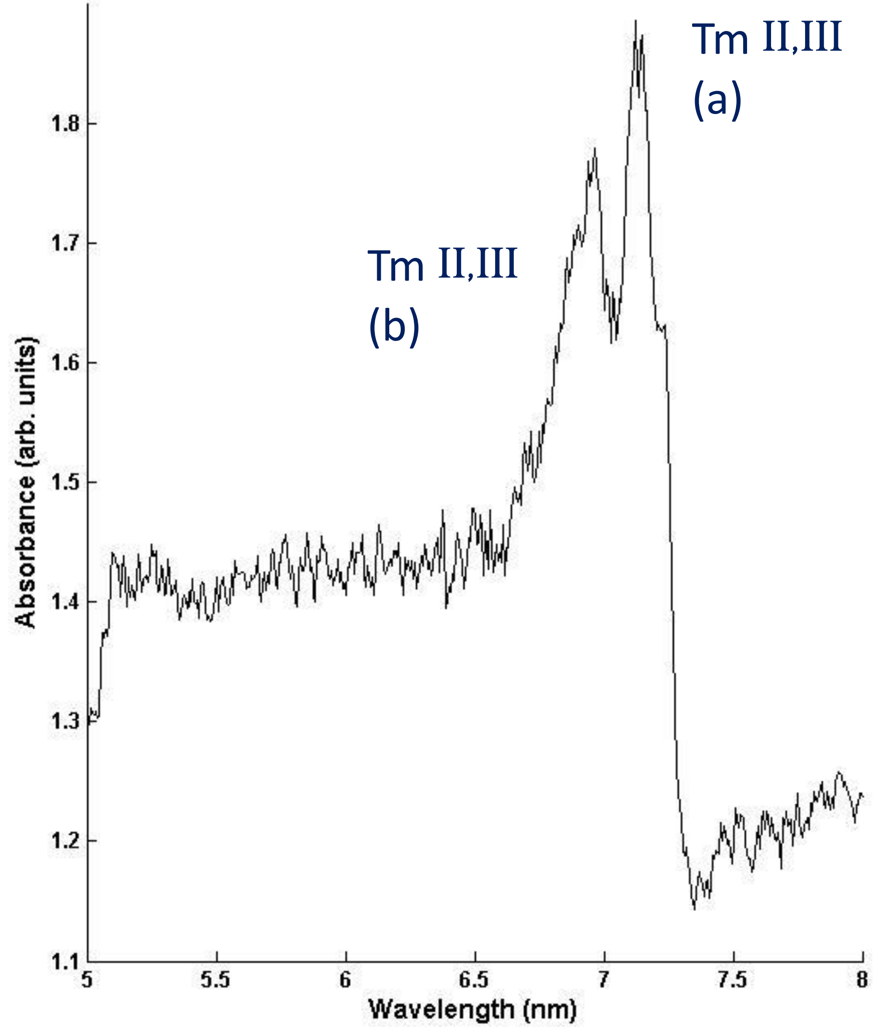


400 ns delay

Thulium; 4d-4f, 400 & 200 ns

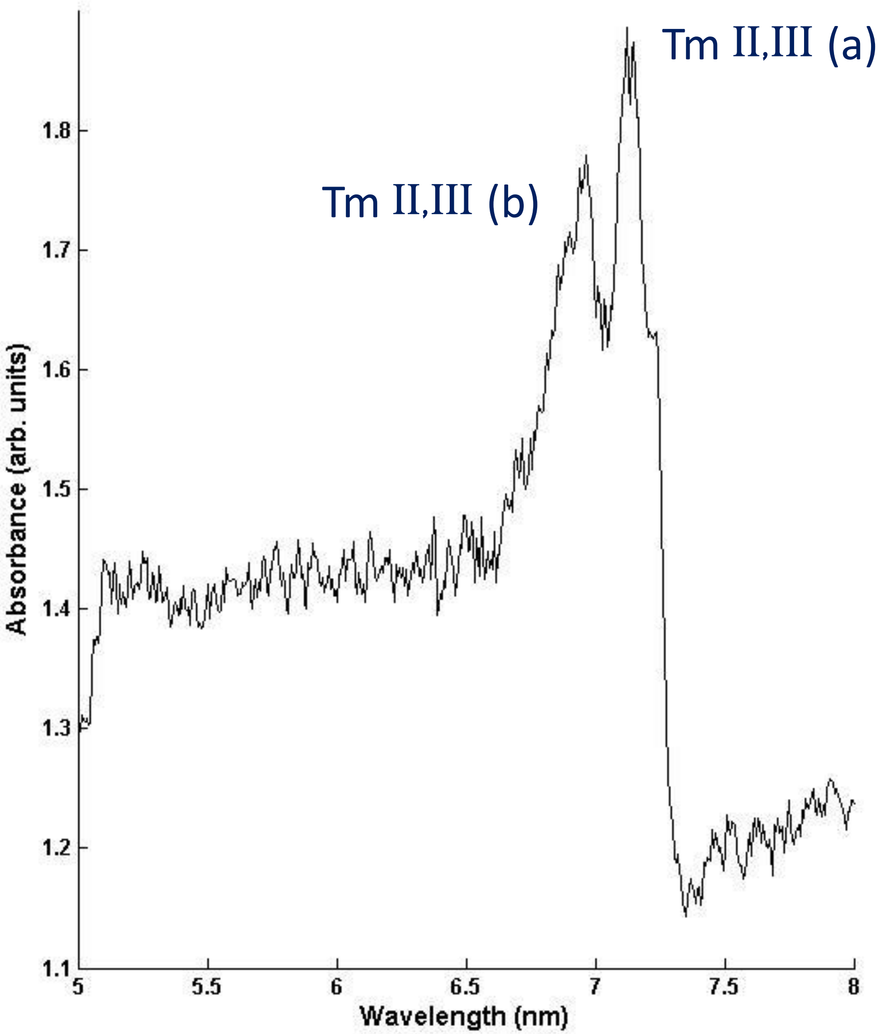


400 ns delay

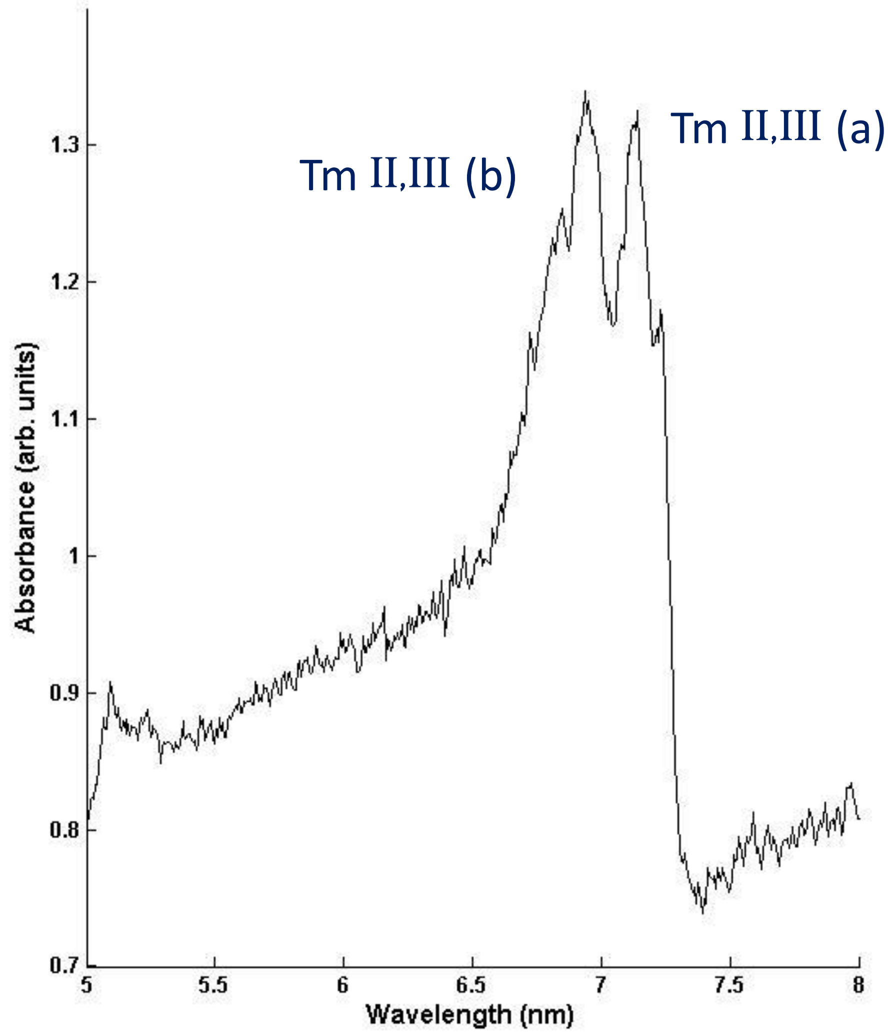


200 ns delay

Thulium; 4d-4f, 200 & 100 ns

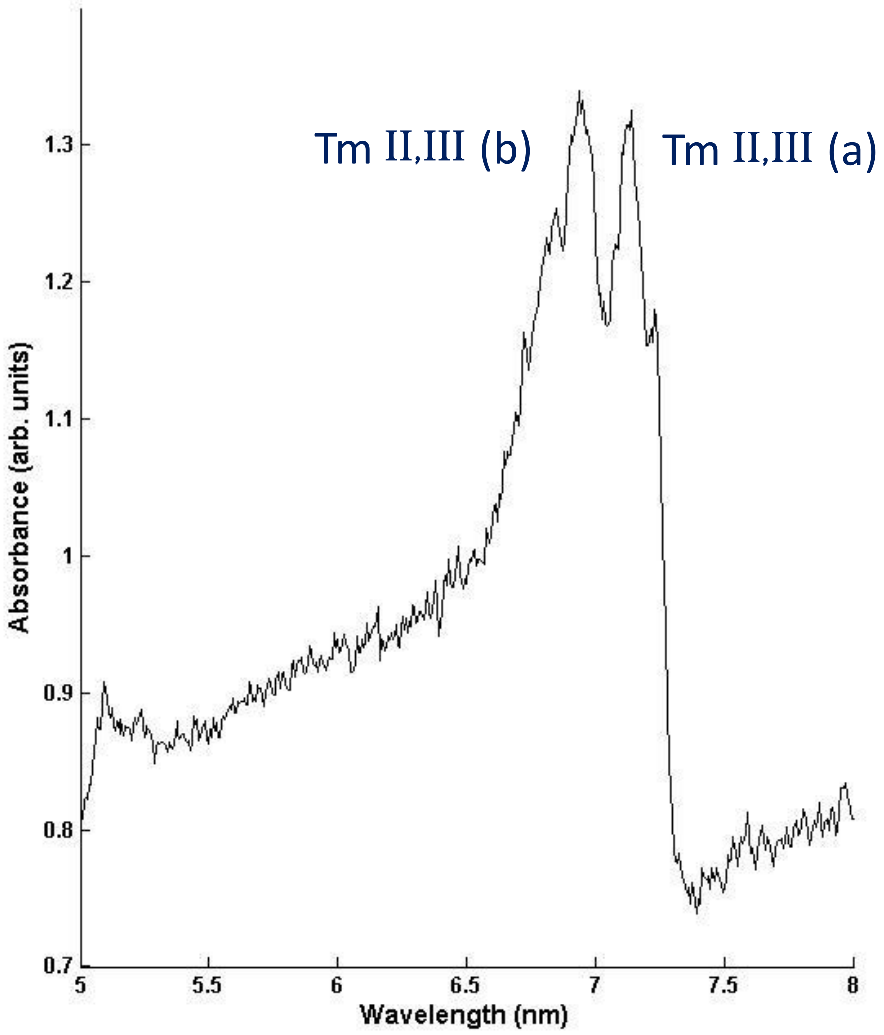


200 ns delay

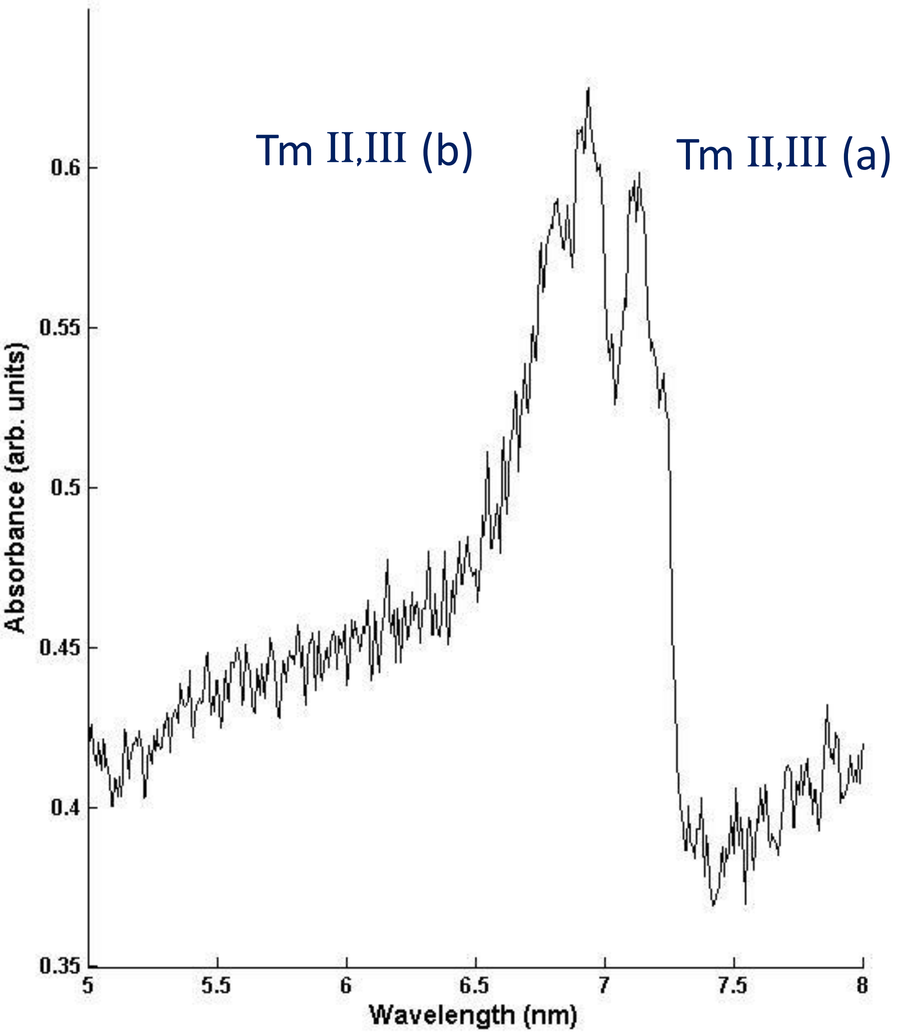


100 ns delay

Thulium; 4d-4f, 100 & 50 ns

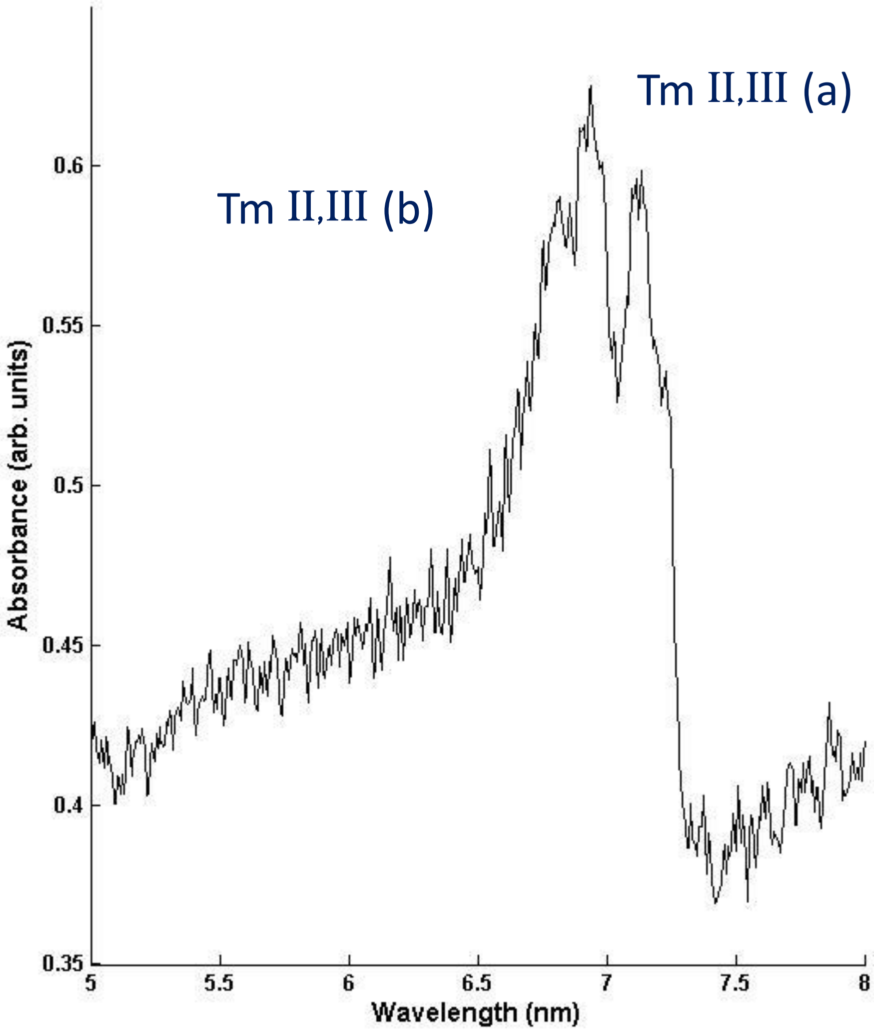


100 ns delay

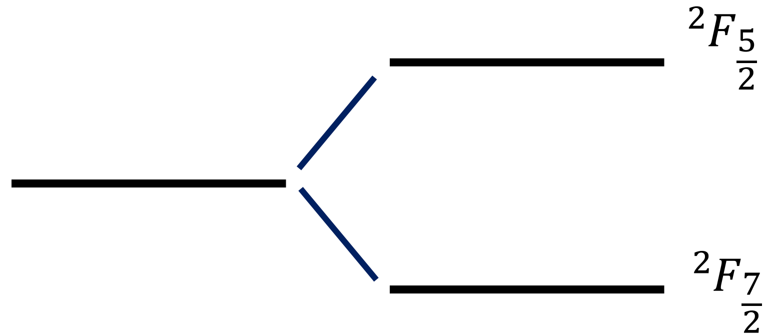


50 ns delay

Photoabsorption of Thulium; 4d-4f transitions



50 ns delay

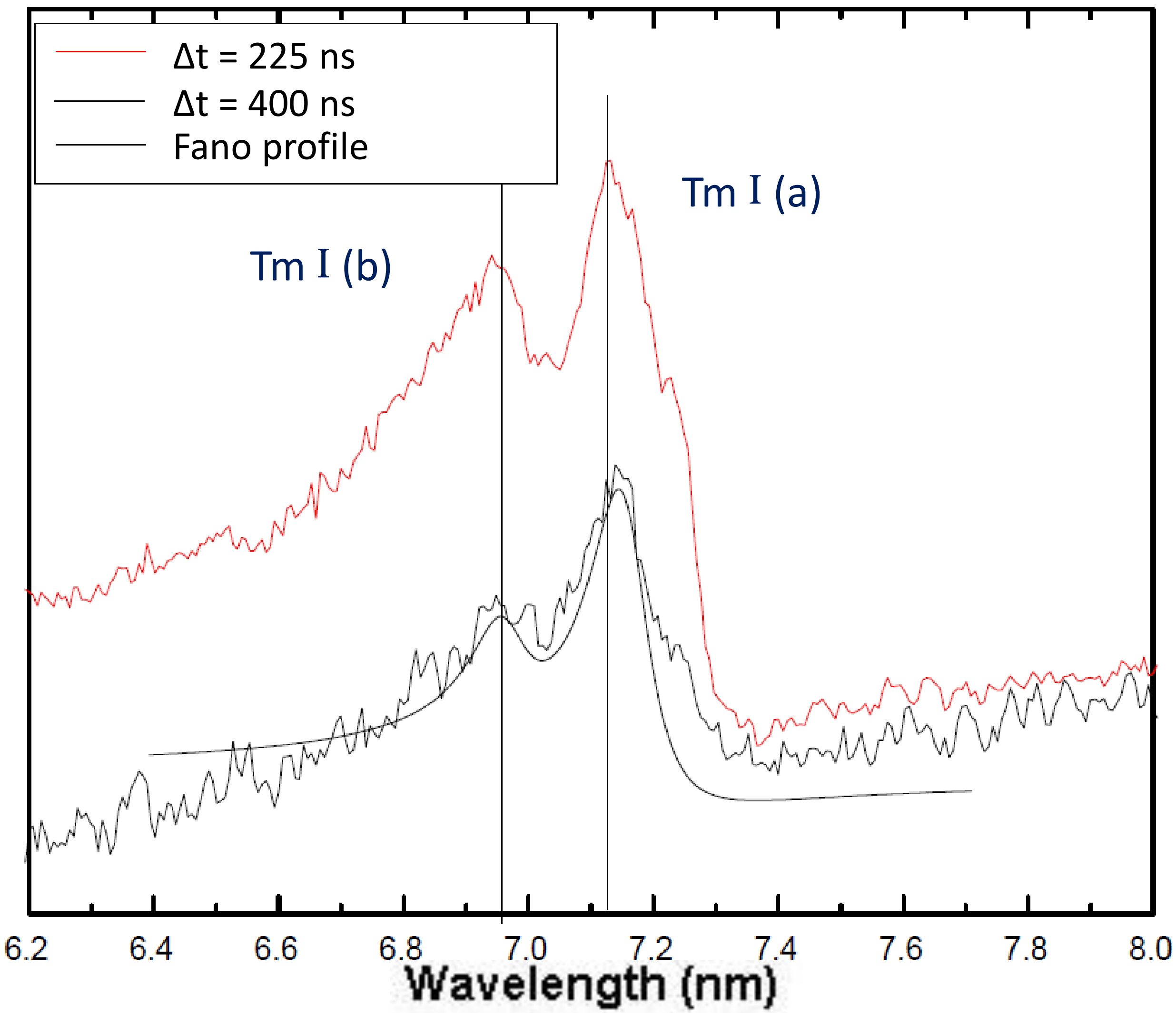


Tm I (a) $4d^{10}4f^{13}\,{}^2F_{\frac{7}{2}} \longrightarrow 4d^{9}4f^{13}\,{}^2D_{\frac{5}{2}}$

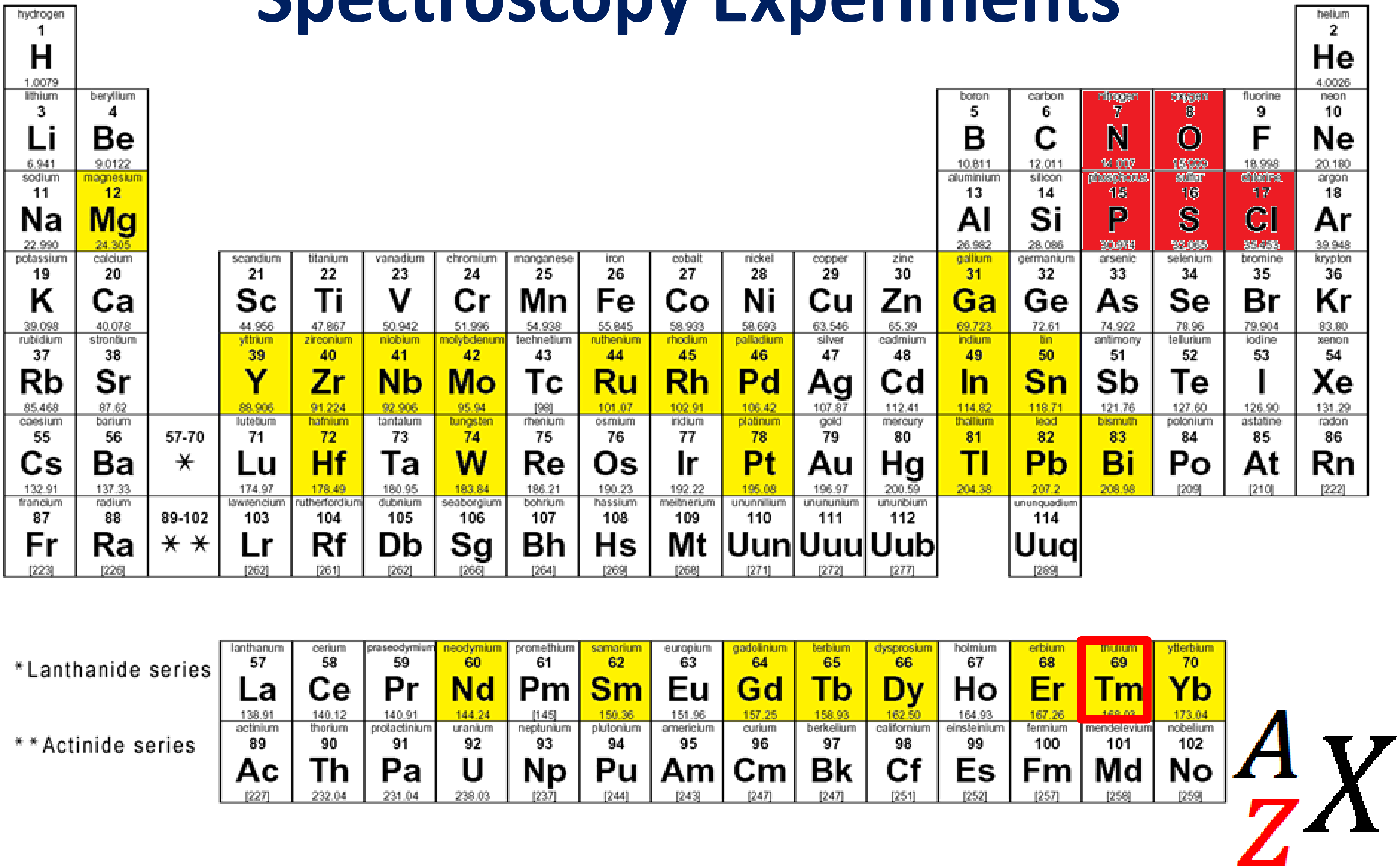
Tm I (b) $4d^{10}4f^{13}\,{}^2F_{\frac{5}{2}} \longrightarrow 4d^{9}4f^{13}\,{}^2D_{\frac{3}{2}}$

Tm I	$4p^64d^{10}5s^25p^66s^24f^{13}$
Tm II	$4p^64d^{10}5s^25p^66s4f^{13}$
Tm III	$4p^64d^{10}5s^25p^64f^{13}$
Tm IV	$4p^64d^{10}5s^25p^64f^{12}$

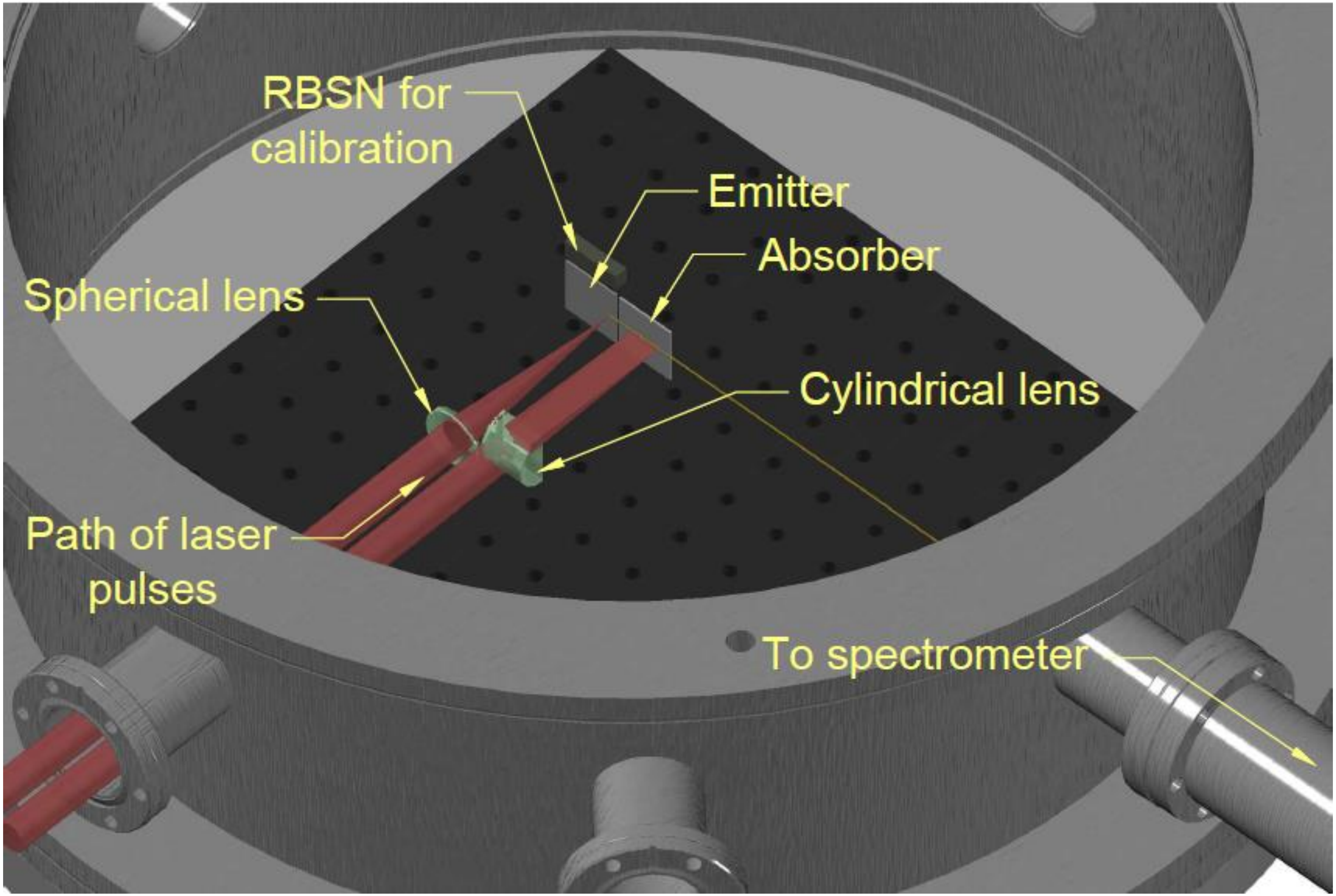
Photoabsorption of Thulium; 4d-4f transitions



Targets to be used for Absorption Spectroscopy Experiments



Photoabsorption Set-up



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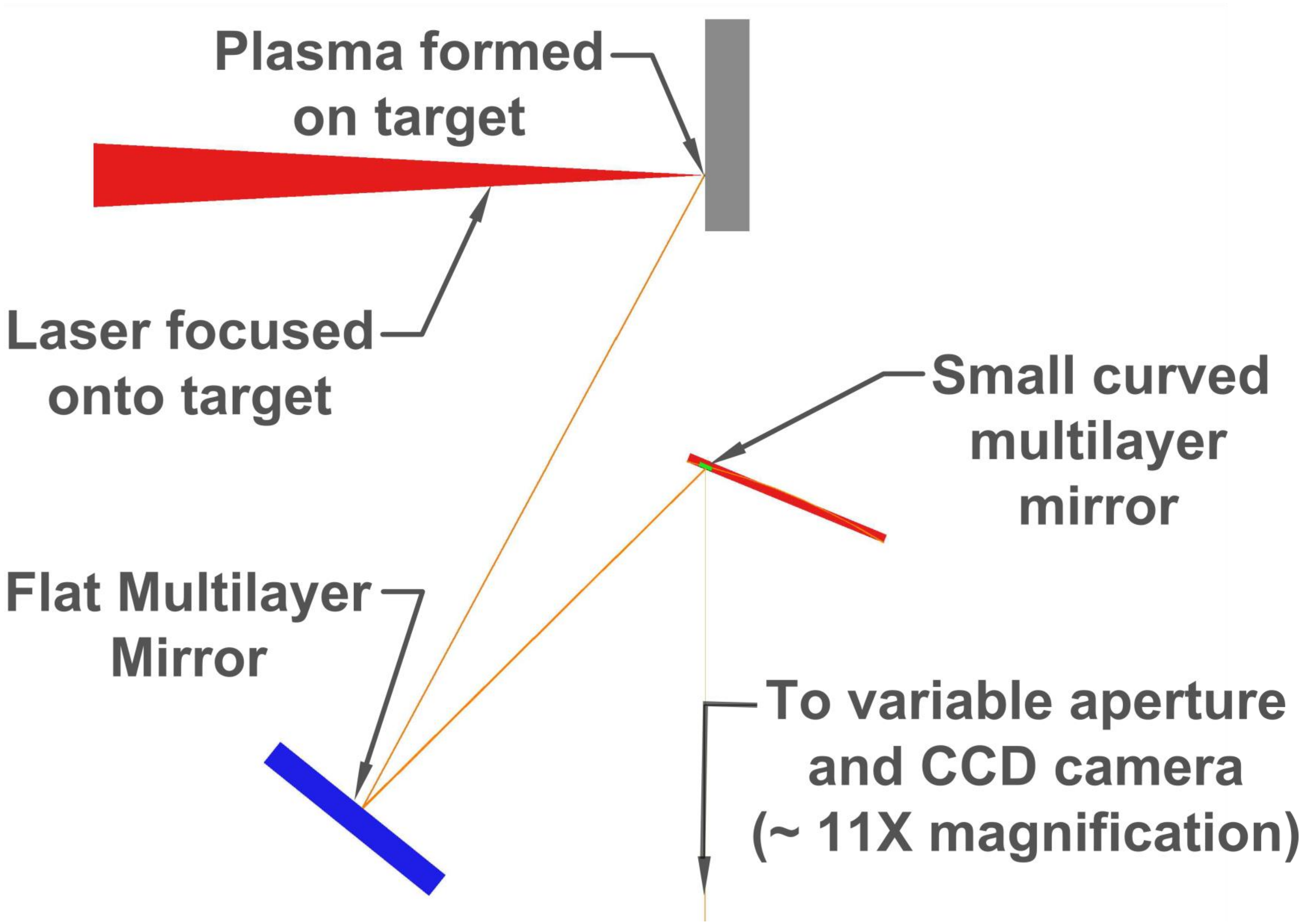
Imaging Plasmas in the Soft X-Ray Region Using Multilayer Optics



Future Work & Conclusions

Main focus will be on producing *small-diameter, high-brightness* plasma sources in the soft X-ray region by;

- Various high-energy, pulsed lasers with pulse lengths from 30 fs to 100 ns will be used to create plasmas for comparison to the 180-ps laser.
- Imaging Plasmas in the soft X-ray region with pinhole camera and multilayer mirrors.
- Absorption Spectroscopy of low-Z elements.

Thank You!

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